Compact EUV Source for Metrology and Inspection

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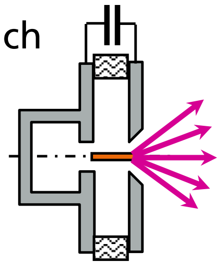
Overview

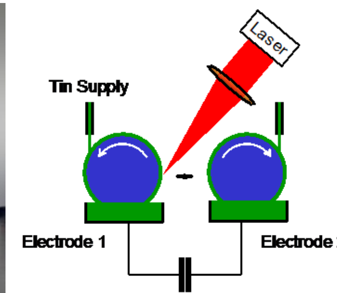
- Introduction
- Xenon based EUV Source FS5420
- Consideration on 6.x nm emission
- Recent progress on lifetime and power scaling
- Dose control of brilliance

EUV Source Activities at Fraunhofer ILT

HCT pinch plasma

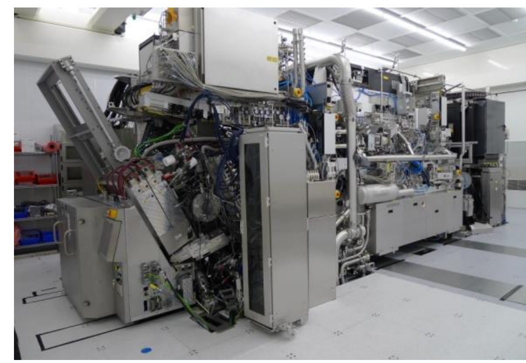


Tin vacuum arc

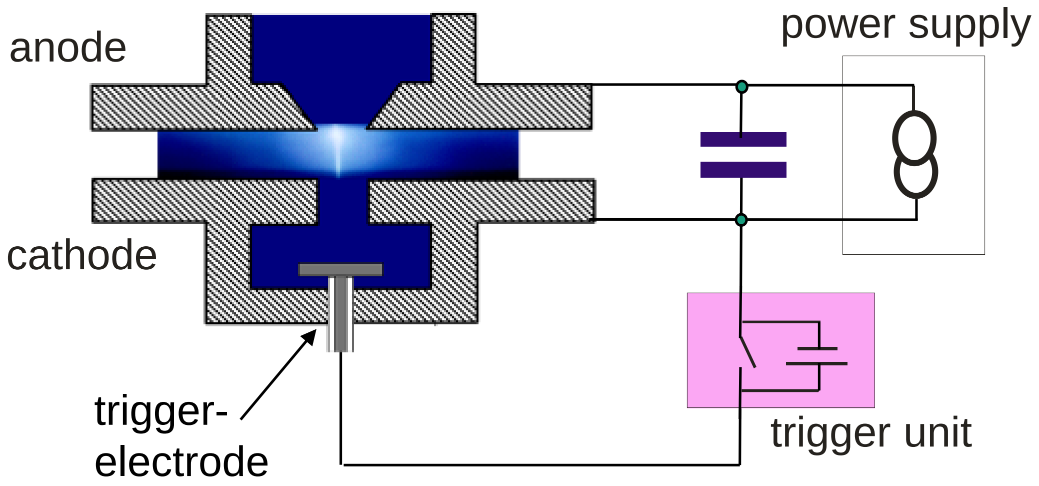


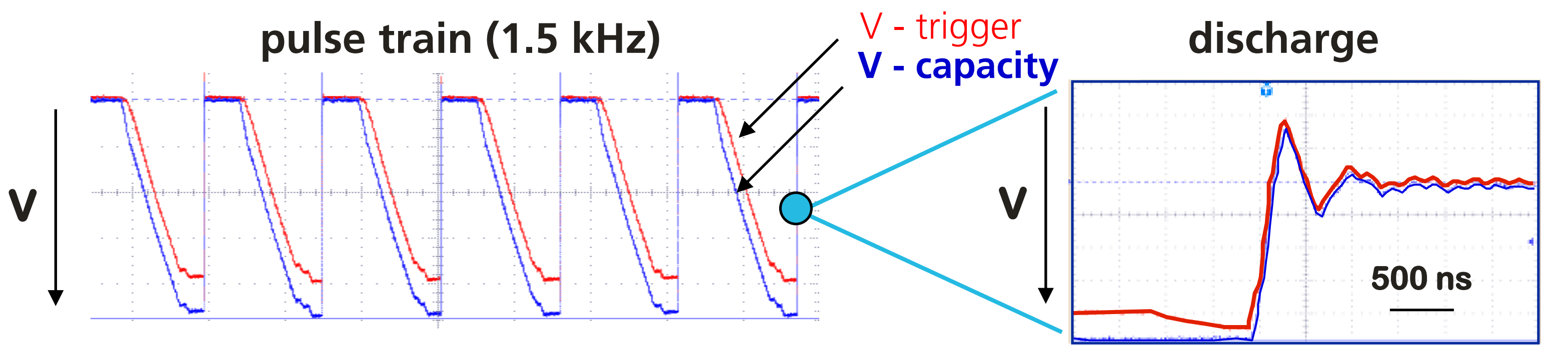
Sources for Aachen University

- Water window microscopy (2.9 nm)
- Nano patterning
- Coherent diffraction imaging
- EUV microscopy
- Photo electron spectroscopy



Hollow Cathode triggered Pinch Plasma





Fraunhofer ILT Source : FS5420

- Standard Mode

  Inband Power : > **20 W/2πsr**

  EUV pulse energy : 2,2 mJ/sr

  typ. repetition rate : 1500 Hz

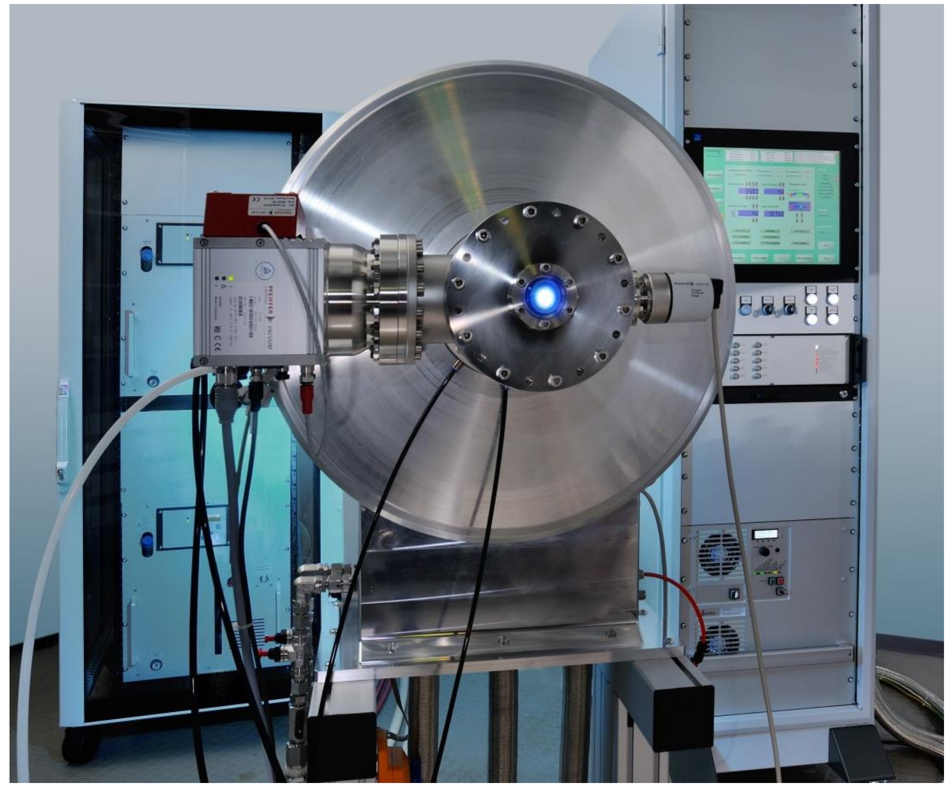
  ave. peak brightness : 8 W/mm^2sr

- High Pulse Energy Mode

  Inband Power : < 10 W/2πsr

  EUV pulse energy : > **4,0 mJ/sr**

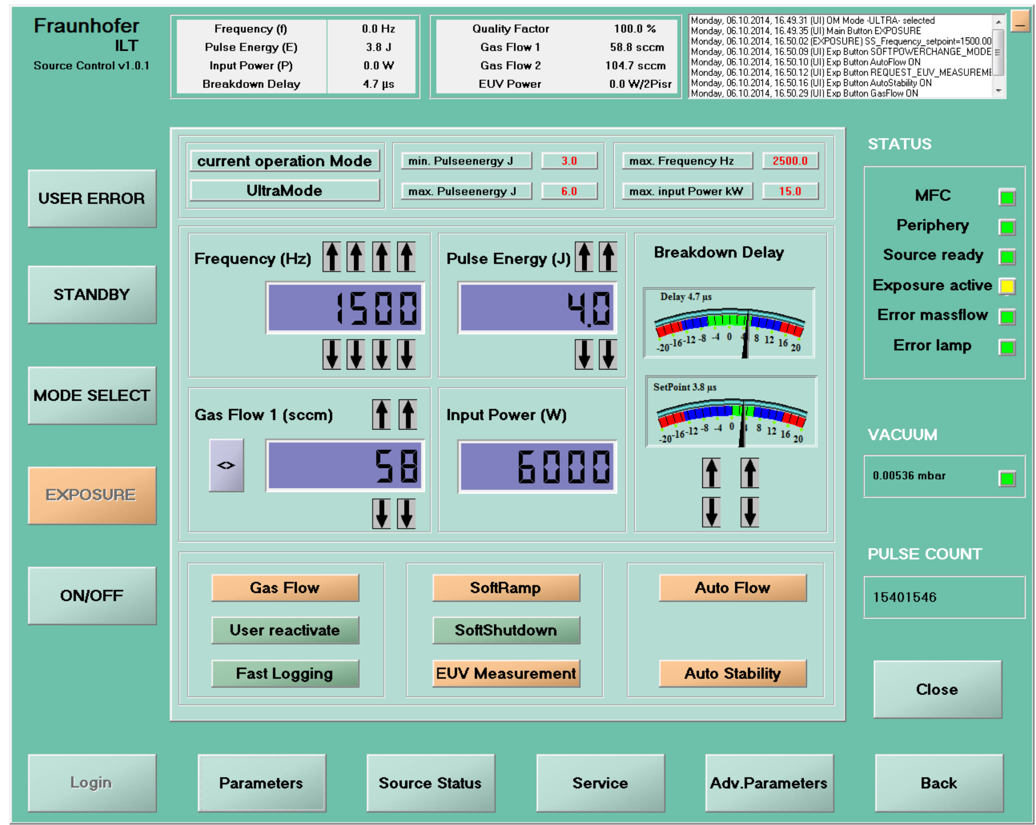
  typ. repetition rate : < 400 Hz



EUV source including power supply, control unit & chillers

HMI - Software

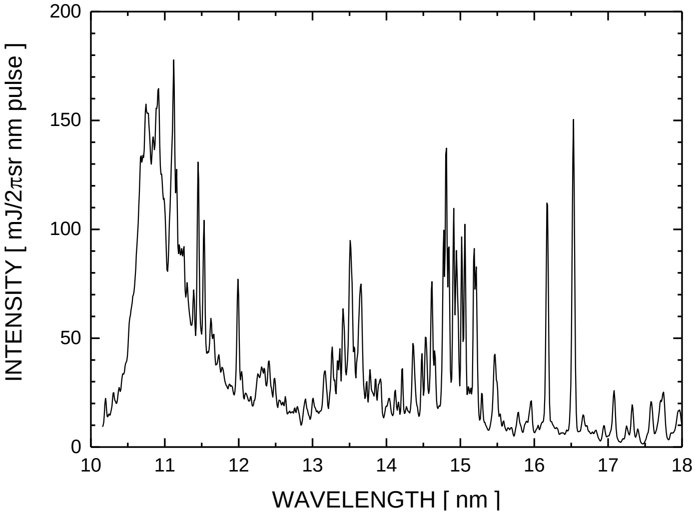
- repetition rate and pulse energy selectable in pre-defined ranges
- gas flow automatically adjusted according breakdown delay
- option for soft ramping up and down of input power
- display of measured frequency and power
- measuring and display of missing pulses (Quality Factor)
- option for EUV power monitoring and dose-control
- fully accessible via Ethernet / Fieldbus



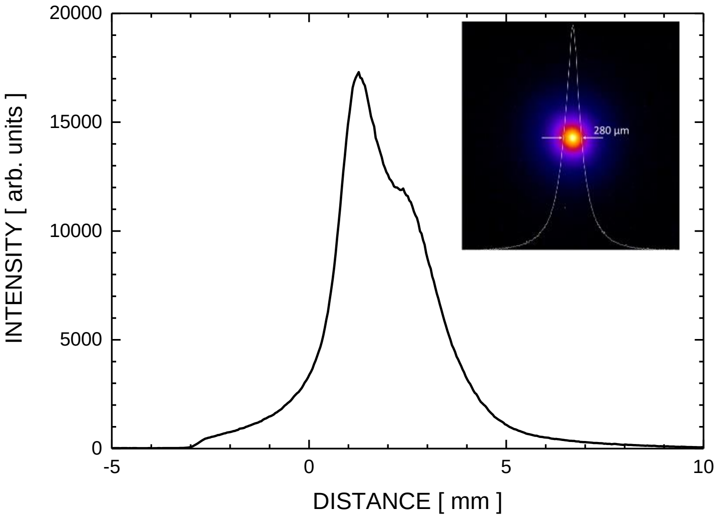
Emission Characteristics

- EUV source dimensions:
  diameter (FWHM) : < 300 µm
  length (FHWM) : ~4 mm
- stability of diameter : ~ 4 %
- spatial stability : < 7 µm
- pulse duration : 50 – 100 ns
- power stability : 1-3 %
  (100 pulses moving average
  over 10 minutes without dose control)

Typical FS5420 emission spectrum

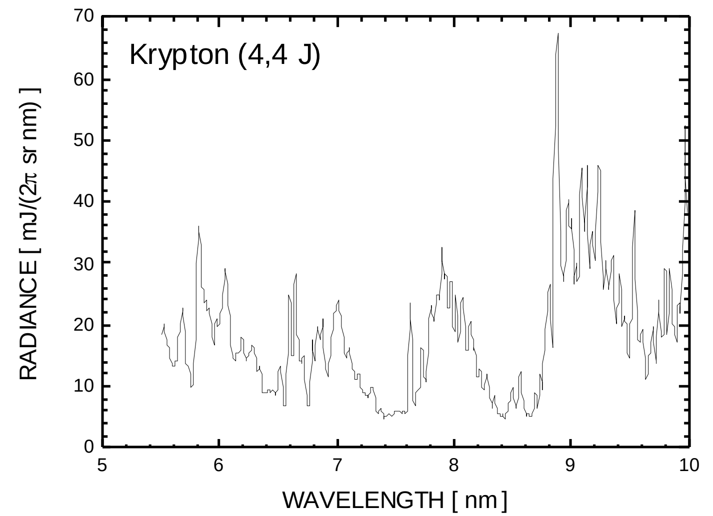


Axial and radial emission profile

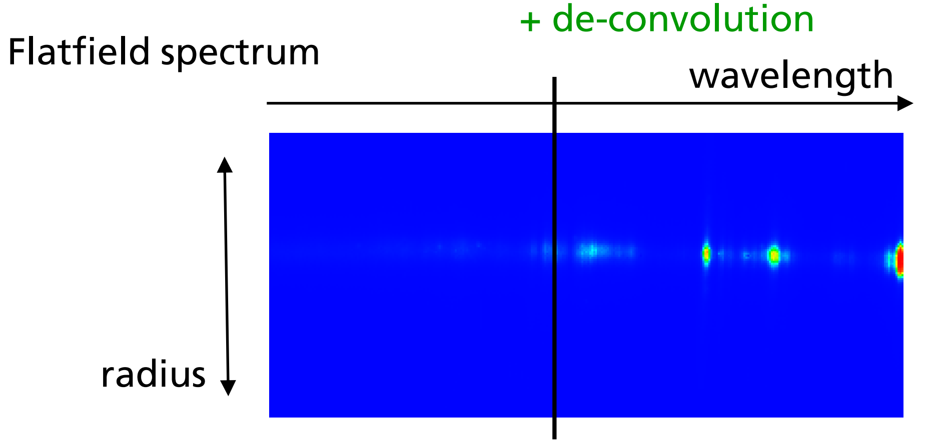


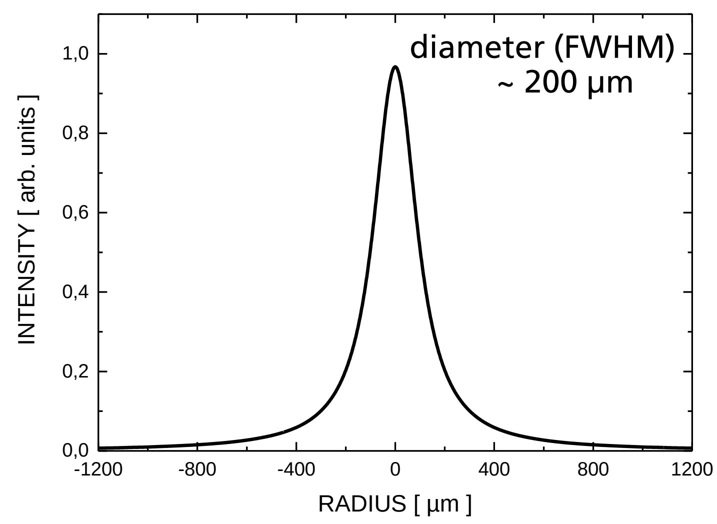
Emission around 6.x nm

- Contributions from 4d-4f transitions around KrX
- Emission between 6-7 nm at 4,4 kW input power : ~ 15W/2πsr
- Suitable for irradiation damage studies or optics characterization



Line scan
+ de-convolution

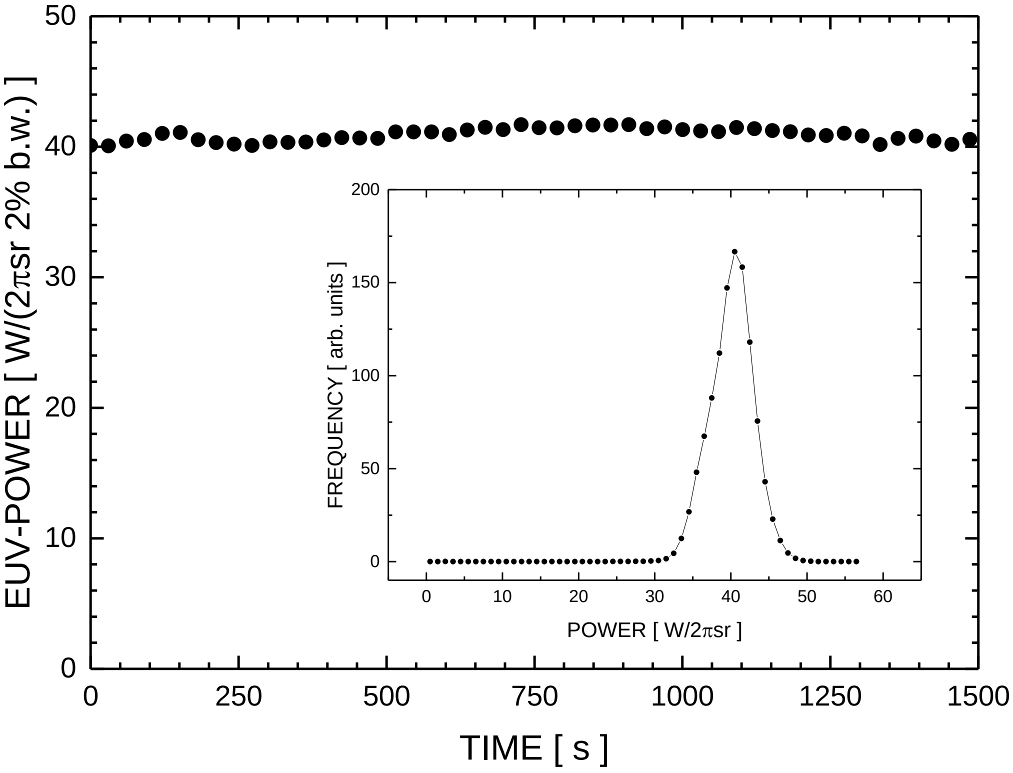




Power Scaling: FS5420 in 40 W - Operation

- average input power:
  13 kW
- repetition rate:
  2500 Hz
- peak brightness:
  ~12 W/mm²sr
- pulse-to-pulse standard deviation:
  6,8 %

EUV inband power during a 30 min run



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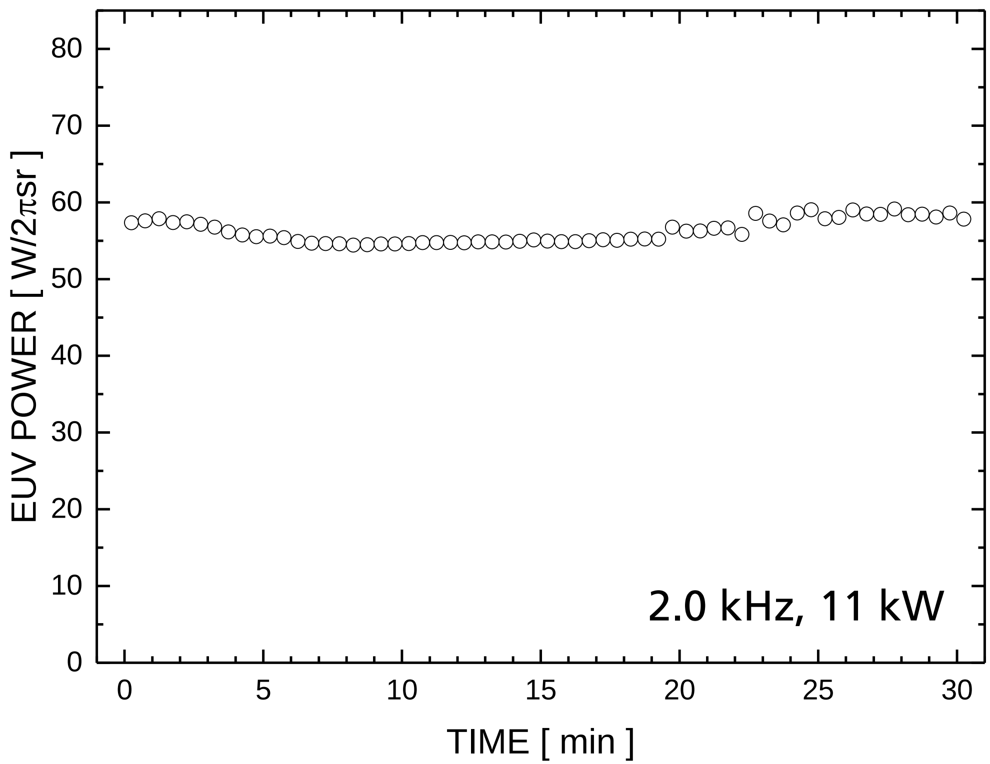
Power Scaling: FS5420 in 55 W - Operation

EUV inband power during a 30 min run



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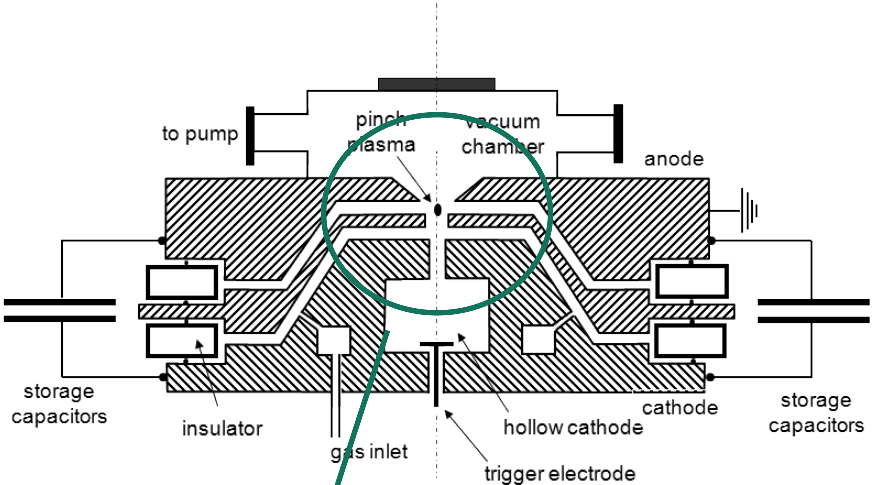
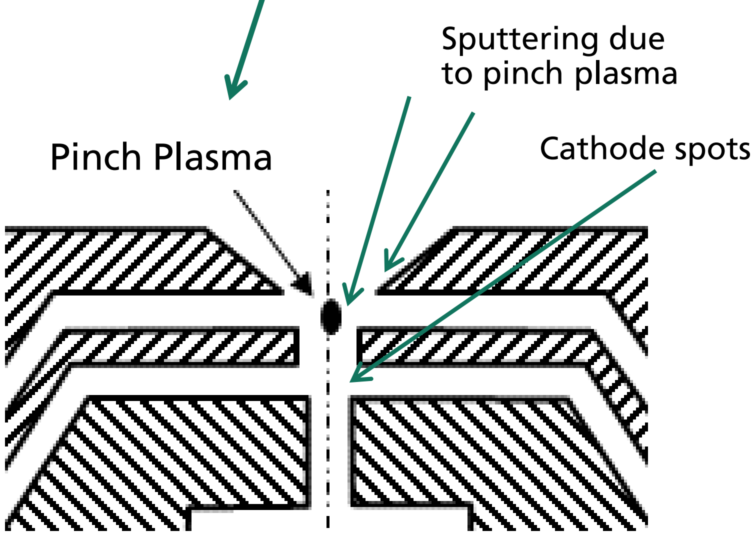
Source Development Aspects



- better understanding of origin of decrease of CE and performance during operation
- reduction of erosion by choosing sputter resistive material
- current achievement for the cathode: **>800 Mshot** and still running



Comparison of Mo and W-based cathode after same number of Mshots

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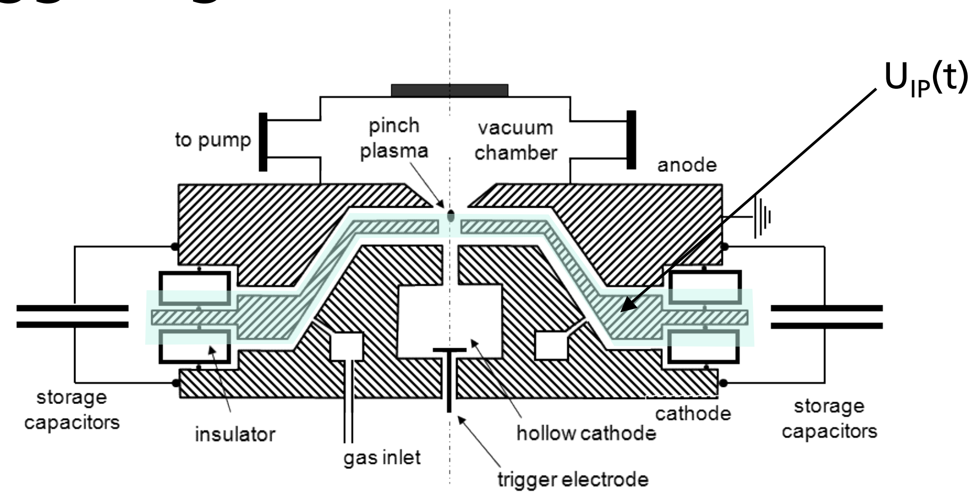
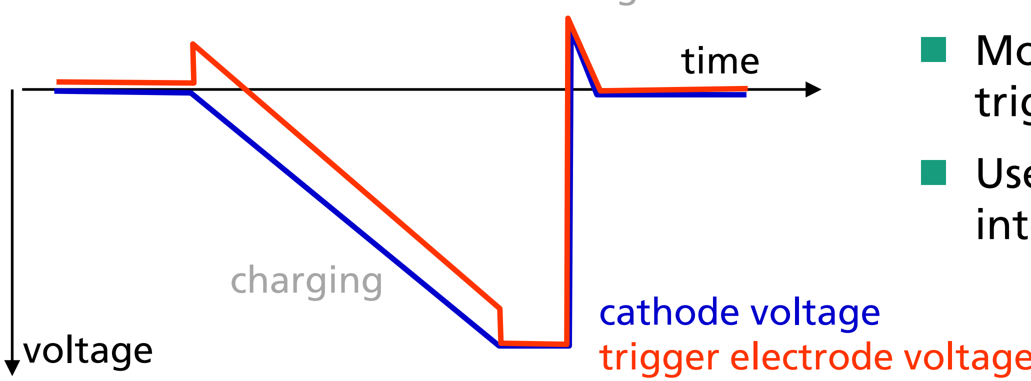
Advanced Triggering



Conventional triggering



Advanced triggering

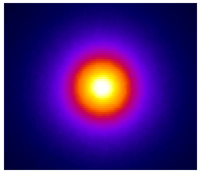
- More sophisticated $U_{trigger}(t)$ at trigger electrode
- Use of additional potential at intermediate electrode $U_{IP}(t)$

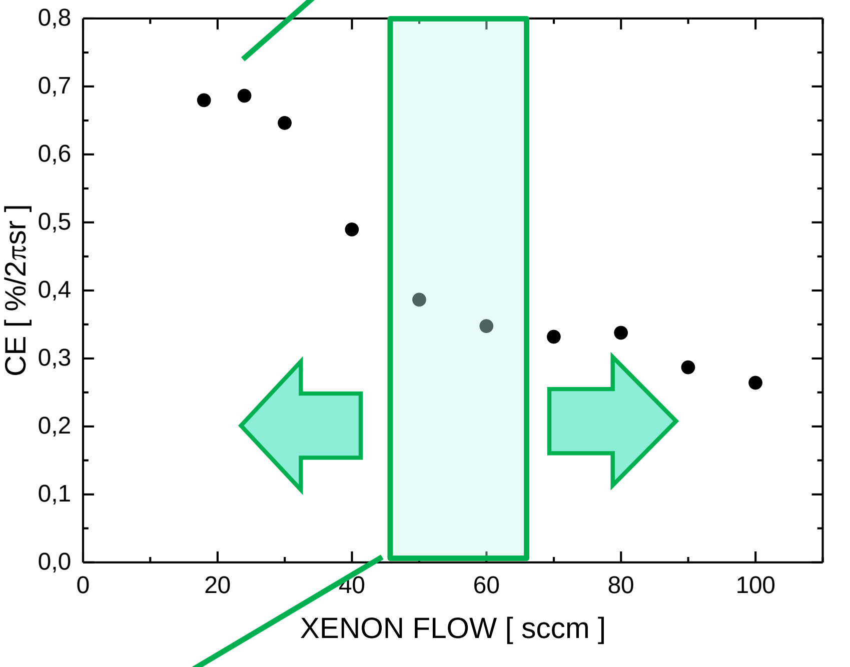
Increase of operation window

- larger process window for Xe- flow due to **advanced triggering**
- higher tolerance towards electrode erosion
  (tested electrodes had >150 Mshot)
- higher CE (~0.7 %) at lower gas flows achievable
- 13.5 nm inband power at 6 kW input:

  ~ 40 W/(2πsr)
- 13.5 nm inband brightness at 6 kW input:

  ~ 12 W/(mm²sr)





Former process window

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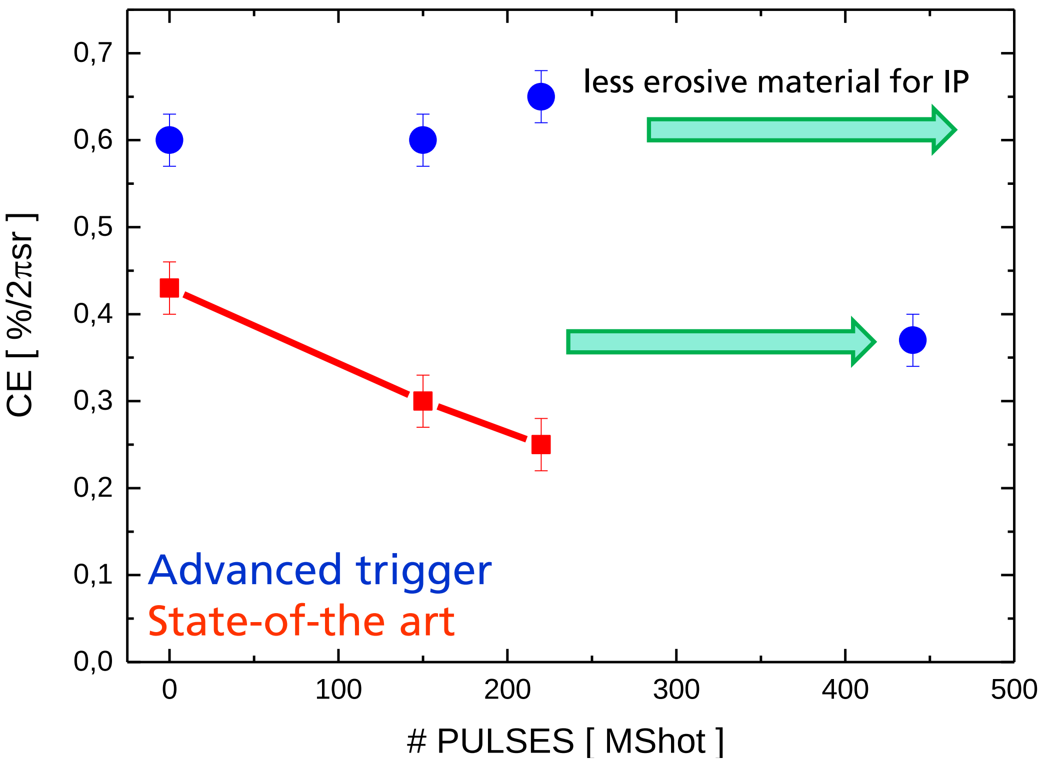
Increase of maintenance interval

- wear of IP (Intermediate Plate) is mainly determining the source performance
- Xe flow increases with wear of IP
- higher flow lead to lower CE and reduces the working range
- advanced triggering allows operation at lower Xe flow with increase of CE
- **1 Gshot** maintenance interval with advanced trigger expected

Intermediate Plate (IP)

Comparison of IP's with different lifetime



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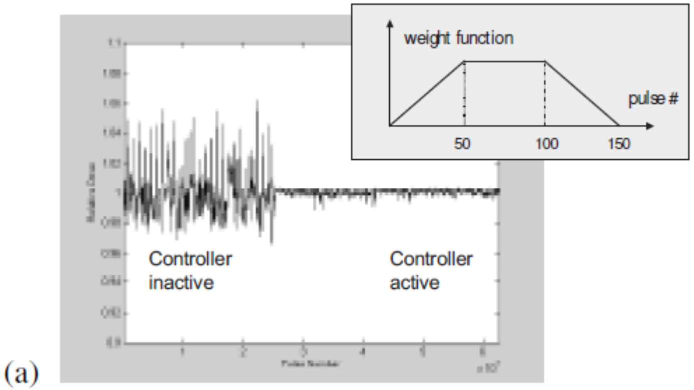
Demonstration of Dose Control of Inband-Power



Dose control at Philips-EUV Xenon source for ASML alpha-tool

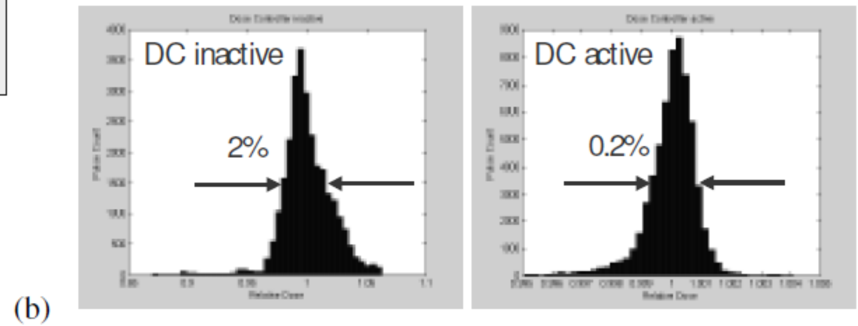


Figure 4: Effect of the dose control system. (a) Dose values over 60000 subsequent pulses. (b) Histograms over about 50000 shots with and without dose control system.The dose stability is improved by a factor of 10.

Ref. : Pankert et al., SPIE 2005

- measurement of inband EUV for each pulse
- assumption of linear behavior of EUV pulse energy with input pulse energy
- variation of input pulse energy for each pulse
- expected dose stability within window of **N** pulses (σ: standard deviation)

without dose control	: $\sigma / \sqrt{N}$
with dose control	**: σ / N**

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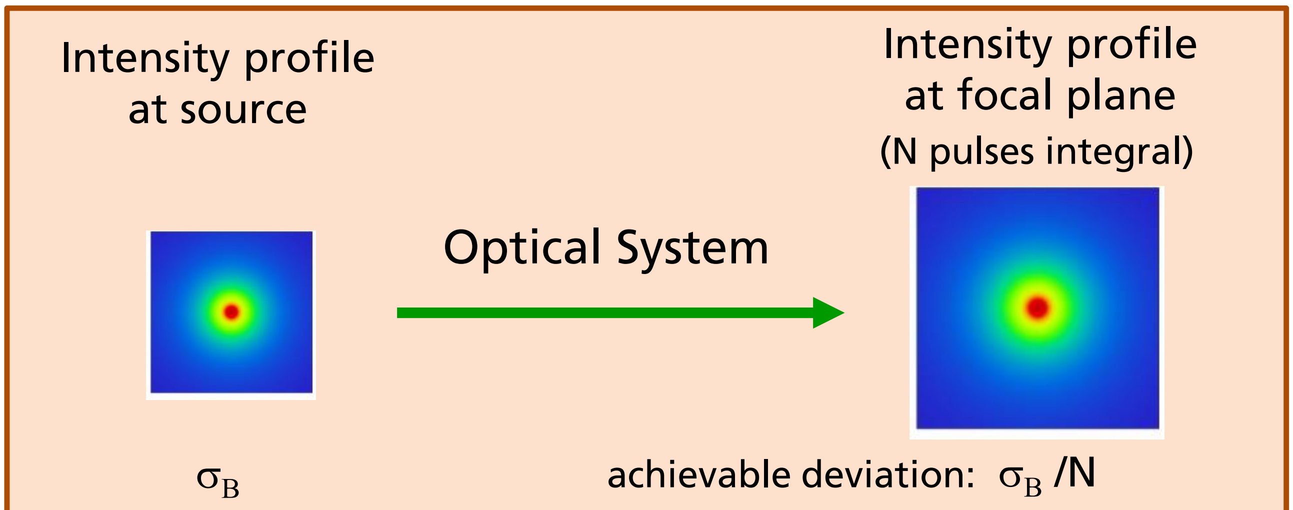
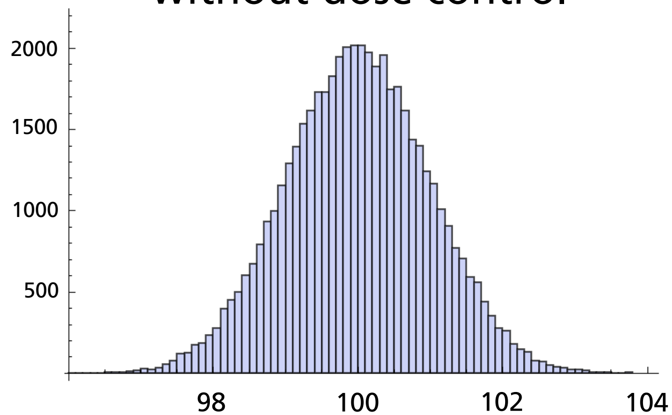
Dose Control of Brilliance : Task

- Potential improvement of $1/N^{1/2}$ allows for relaxed conditions for source stability σ_B
- Look for suitable parameter with high correlation, ρ, with source brilliance
- Built up of pulse-to-pulse metrology for this parameter
  (e.g. total inband photon flux)



Dose Control of Brilliance : Requirement on Correlation

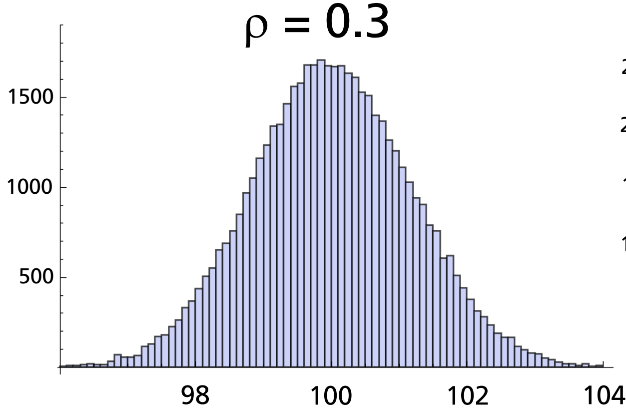
without dose control



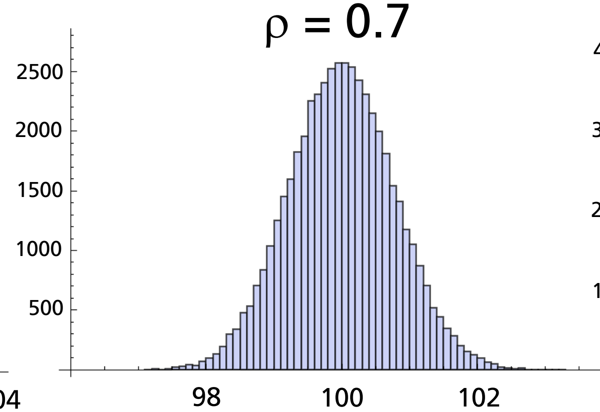
- Simulation for Gaussian Distributions <x>, <y> with **σ = 10 %** each and average values of **1.0**
- x measured parameter, e.g. inband photon flux
- y controlled parameter, i.e., source brilliance
- Integration over N = 100 pulses
- improved dose stability requires $\rho > 0.5$

with dose control

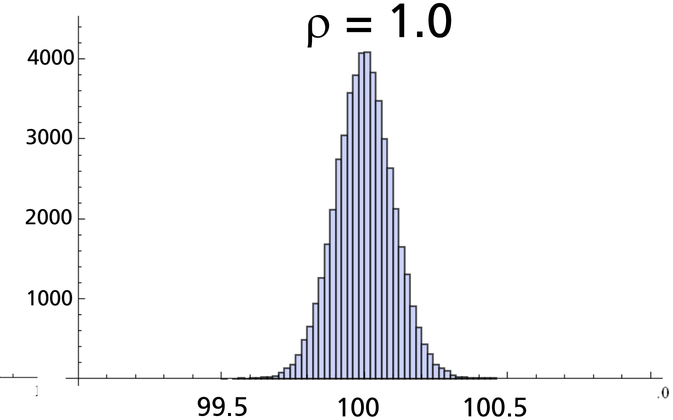
$\rho = 0.3$



$\rho = 0.7$

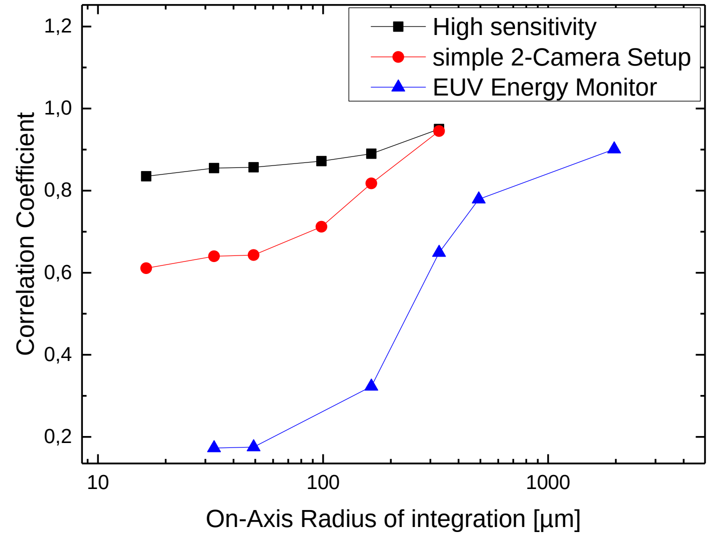


$\rho = 1.0$



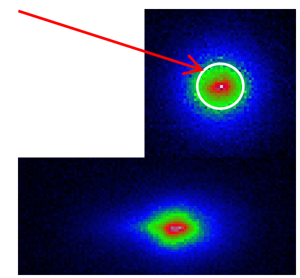
Dose Control of Brilliance : Correlation Parameter

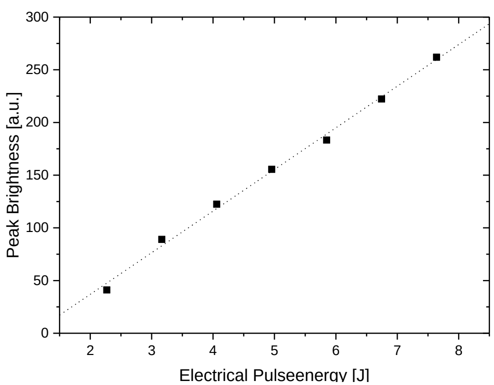
- Proof of concept experiment at 1 kHz & 4 J input power
  Fast EUV-inband Cameras at 2,5 Hz pulse picking
- Metrology:
  Camera on-axis
  Camera off-axis
  EUV Energy Monitor off axis
- Evaluation at fixed pixel-position
- High sensitivity setup without Zr-Filter at off-axis camera
  -> some visible light may still be interfering
- High Correlation Coefficient ρ>0,85 for Spot with 60 µm diameter



Single-shot Camera images of pinch:
On-Axis

Off-Axis





Linear Brightness – Pulse energy dependence allows active control of dose collected from small NA

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Summary

- New generation FS5420 EUV source is available at Fraunhofer ILT
- Improvements in operation by software, e.g. error detection and automatic adjustment of operation parameters
- Ongoing basics investigations on lifetime and power scaling
- Major improvements have been demonstrated in key experiments by means of advanced triggering
- Next generation **FS5440** – 40 W EUV source in development:
  Combining long-life electrodes with high CE of new trigger system